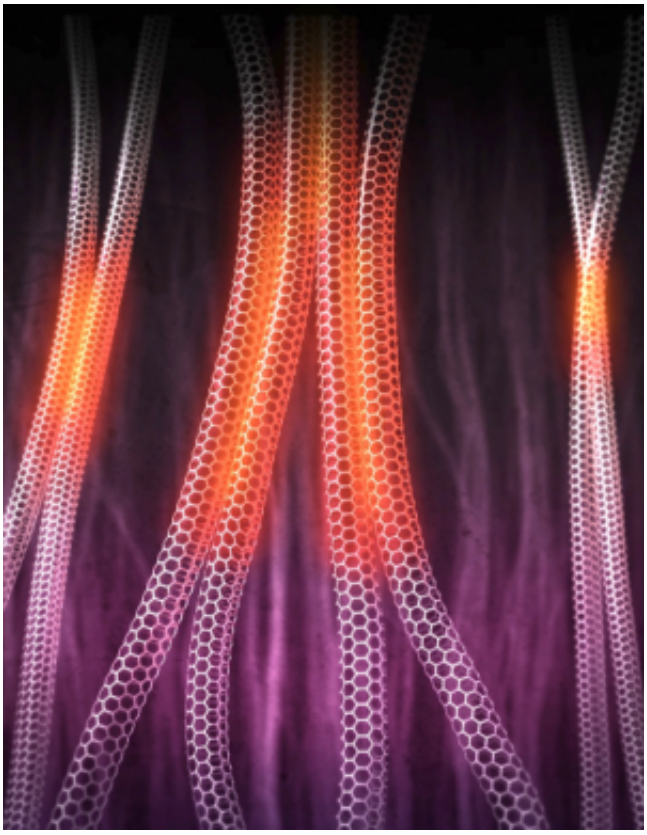
Engineers show how to optimize carbon nanotube arrays for use in hot spots

December 2 2013



This is a stylized rendition of single walled carbon nanotubes that are just one atom thick in diameter. The red zones show where the attraction caused by van der Waals forces has bent or "zipped" two adjacent CNTs together. Credit: Alex Jerez.

When engineers design devices, they must often join together two

materials that expand and contract at different rates as temperatures change. Such thermal differences can cause problems if, for instance, a semiconductor chip is plugged into a socket that can't expand and contract rapidly enough to maintain an unbroken contact over time.

The potential for failure at such critical junctures has intensified as devices have shrunk to the nano scale, bringing subtle forces into play that tug at atoms and molecules, causing strains that are difficult to observe, much less avoid.

Writing in the *Proceedings of the National Academy* (*PNAS*), Stanford engineers report on how to create carbon nanotube structures that remain strong and supple at these critical interfaces where thermal stress is intrinsic to the design.

"Think about the heat sink for a microprocessor, " said senior *PNAS* author Kenneth Goodson, Professor and Bosch Chair of Mechanical Engineering at Stanford. "It is exposed to high heat fluxes for long periods of time, and repeated instances of heating and cooling."

At present materials like solder and gels have been used at such junctions. But as electronics continue to shrink, more electrical power gets pushed through smaller circuits, putting materials under ever increasing thermal stress.

"Solder has high thermal conductivity, but it's stiff," Goodson said, explaining why his lab continues to experiment with single-walled carbon nanotubes. Just before this *PNAS* contribution, his team described the favorable thermal properties of nanotubes in an article for *Reviews of Modern Physics* (Vol. 85, pp. 1296-1327).

Nanotubes are infinitesimally thin strands of carbon atoms that have the potential to be efficient at conducting heat. They are also strong for their

size, and can be flexible depending on how they are fabricated.

The Stanford *PNAS* paper was based on experiments and simulations designed to reveal how to create carbon nanotube structures (CNTs) with the optimal blend of all three characteristics – strength, flexibility, and heat conductivity – that are required in critical junctures where thermal stress is a fact of life.

The Stanford paper represents about five years of teamwork centered in the Stanford Mechanical Engineering Department including experiments led by first author Yoonjin Won, who was then a doctoral student in mechanical engineering.

She used a variety of existing techniques to assemble CNTs with different structural characteristics, and then measured the flexibility (also called modulus) and thermal conductivity of each structure to look for the optimal structure.

Left to nature, the carbon atoms that form CNTs will create structures that – if we could see them—resemble a bowl of spaghetti.

But Won worked with collaborators at the University of Tokyo to create CNTs that grew up relatively straight, like grasses. Some degree of entanglement still occurred. Precise control of CNT growth remains beyond the reach of science.

Nevertheless, Won's experiments showed that longer CNTs, grown less densely together, seemed to have the best combination of flexibility, heat conductivity and strength, for use in electronics and other industrial applications where thermal stress is expected.

To some degree her findings represent a tradeoff. Denser, shorter CNT structures are stronger and more efficient at dissipating heat. But they

are also more entangled and stiffer. Won's experimental results showed that as CNT strands grew longer, they tended to grow straighter and were less tangled, which increased the flexibility of the structure, albeit with some acceptable losses in the other two parameters.

Because the ultimate goal of this work is to reveal how to optimize CNT structures for use as thermal transfer materials, the Stanford team built a computer simulation of the CNT assembly process with an eye toward understanding how the CNTs became bent and entangled despite efforts to grow them straight.

Work on the simulation was led by Wei Cai, an Associate Professor of mechanical engineering at Stanford, who holds a courtesy appointment in materials science and engineering. The Stanford scientists wanted to understand the manner in which van der Waals forces influence the growth of CNTs.

These forces are named for the Dutch physicist who first described the weak attractions that exist between molecules – attractions that could not be explained by other known forces such as the chemical bonds that result when atoms share electrons.

Cai said that whereas van der Waals forces may not be critical in other types of structures, carbon nanotubes are so thin—a mere atom or so thick in diameter—that these minute forces could fundamentally affect them.

That is in fact what the simulation showed. Imagine a CNT attempting to grow straight, only to be bent to one side by the van der Waal attraction of another CNT crossing near its top, and perhaps bent to the other side by a different CNT that nears its bottom.

Taken together, the experimental results and computer simulation

reinforce the findings that longer, less entangled CNTs would offer the best mixture of the desired characteristics strength, flexibility and heat transfer. But due to the van der Waals forces operating on these atom-thick carbon tubes, engineers are going to have to accept some bending and irregularity as they strive to create workable, though less than ideal, structures for dissipating heat.

"When you hear about nanotechnology it's usually about the superlatives, the strongest this, the thinnest," Goodson said. "But we think is the answers will lie in finding the right combinations of properties, something that's strong and conducts heat like a metal, but can flex and bend as well."

More information: Zipping, entanglement, and the elastic modulus of aligned single-walled carbon nanotube films, *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1312253110

Provided by Stanford University

Citation: Engineers show how to optimize carbon nanotube arrays for use in hot spots (2013, December 2) retrieved 25 April 2024 from https://phys.org/news/2013-12-optimize-carbon-nanotube-arrays-hot.html

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.